

AD A101707

# Paper Series

SAE Technical

(14) SAE-77-801227

(6)

## Nuclear Hardness Assurance for Aeronautical Systems.

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9 Final draft

(11) at 83  
(12) 20

Aerospace Congress & Exposition  
Los Angeles Convention Center  
October 13-16, 1980

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JUL 21 1981

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WARRENTALE, PENNSYLVANIA 15096

81 7 20 150

REPORT DOCUMENTATION PAGE

SAE Paper No. 801227

NUCLEAR HARDNESS ASSURANCE  
FOR AERONAUTICAL SYSTEMS

Final

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Program Element 11898

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October 1980

SAC/LGME  
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Classification	<input checked="" type="checkbox"/>
Availability Codes	<input type="checkbox"/>
Avail and/or	<input type="checkbox"/>
Special	<input type="checkbox"/>

Nuclear Hardness, Hardness Assurance, Nuclear Survivability/Vulnerability,  
Hardness Maintenance, Aircraft.

This paper addresses nuclear hardness assurance as it relates to system acquisition, prerequisite, prerequisite efforts necessary for an affordable hardness assurance program, and the key aspects of the management of the program.

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# Nuclear Hardness Assurance for Aeronautical Systems

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AIR FORCE SYSTEMS with general war responsibilities must be capable of completing their assigned missions during and after exposure to the hostile environments generated by detonations of nuclear weapons. This system requirement, nuclear survivability, is governed by an Air Force regulation (1)\* which establishes policy for the conduct of the Air Force Survivability Program. Hardness is defined as a measure of the ability of a system to withstand exposure to one or more nuclear environments, and is being specified with ever increasing frequency in new system acquisition programs as well as replacement procurements.

The various phases of a major system acquisition program are depicted in Figure 1. Under each phase are the critical nuclear survivability actions which must be accomplished during that phase. During the conceptual phase, extensive analyses considering mission, scenario, threat, cost, technological capability, and numerous other factors must be conducted to establish nuclear hardness criteria which provide the necessary survivability. During the validation phase, the criteria must be converted into useable system specifications (e.g. a free-field electromagnetic pulse criterion must be related to system shielding requirements and "black-box" connector-pin voltages and

currents). A program plan detailing the approach to satisfying the specifications must also be formulated. During the full scale development phase, designs are developed and verified. Hardness assurance is appropriate during the production phase to ensure that each production system conforms to the hardened design. Hardness maintenance and surveillance programs are established and implemented by the using and maintaining agencies to insure that design hardness is maintained throughout the operational life of the system.

Although each element is a vital part of the survivability program, experience has shown that hardness assurance drives the entire survivability program. It falls between the development phase where one-of-a-kind prototypes are being built --- sometimes on a trial and error basis --- and the deployment phase where hundreds of "identical" units are deployed. An effective and affordable hardness assurance program is strongly dependent on rather extensive prior supportive efforts. These efforts are in addition to those listed in Figure 1. These prerequisite efforts include (a) the formu-

\* Numbers in parenthesis designate references at end of paper.

## ABSTRACT

This paper addresses nuclear hardness assurance as it relates to system acquisition, prerequisite efforts necessary for an

affordable hardness assurance program, and the key aspects of the management of the program.

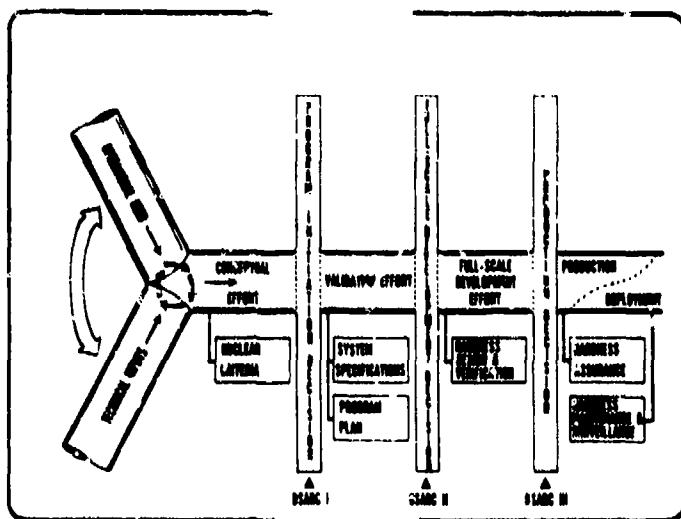


Fig. 1 - System acquisition program phases

lation of a program philosophy, (b) the determination of hardness design margins, (c) the documentation of hardness-critical design details and rationale and (d) the development of detailed parts specifications.

The program philosophy consists of basic ground rules established during the conceptual phase. Since these ground rules influence the remainder of the potentially decades-long survivability program, considerable effort should be expended in their development and refinement. A major consideration in their development is the amount of funds available for the survivability program. Funds availability drives the confidence factor associated with meeting or exceeding the hardness criteria. Most aeronautical systems programs have fallen in the "low cost-medium confidence" category, whereas ballistic missile programs (with no man in the loop) require higher confidences. Considerations in the effort to obtain the maximum hardness at minimum cost include trades between the immediate nonrecurring cost of overdesign versus the recurring cost of tight control over marginally hard systems, selective hardening of only the mission critical subsystems, concentration of emphasis (and funds) on those elements of the system most critical to the overall system hardness, identification of other program requirement which may be synergistic to the hardness requirement and the integration of such requirements into a single approach. (There are numerous examples of such synergisms. MIL STD 1553 (2) relating to digital equipment interfacing results in increased tolerance of digital systems to voltage transients. This increased tolerance is a tremendous boon to gamma rate and elec-

tromagnetic pulse hardening. Other examples are given in references 3 & 4.)

This paper is based on the work done by the authors at the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. The original efforts were documented in a technical report directly oriented toward the B-1 Program (3). (This report was included by reference in the B-1 production contract.) The results were generalized and published in a report (4) available to the general public. This paper summarizes these basic efforts and changes which have occurred in response to several years of experience in applying the basic work to ongoing system acquisitions.

#### NUCLEAR ENVIRONMENTS

The detonation of a nuclear warhead releases tremendous amounts of energy in a very short time period. The purpose of this section is to present a brief discussion of the various nuclear environments resulting from the detonation with particular attention given to those most pertinent to aeronautical systems. Interested readers are referred to Glasstone (5) and to the EMP Awareness Handbook (6) for more detail.

The chain reaction comprising detonation produces energetic photons (X-rays and gammas) and particles (neutrons, alphas, and betas). These primary emanations in turn result in secondary effects, sometimes of more impact than themselves. For example, a high altitude detonation produces gammas which interact with the atmosphere via Compton scattering and generate large numbers of electrons. Electron motion along the earth's magnetic field lines results in radiation of broadband electromagnetic energy. Figure 2 depicts the major primary and interactive environments produced by a detonation.

There are several general categories of Air Force systems depending upon whether they are manned or unmanned, whether they have strategic, tactical or support roles, whether they operate inside or outside the sensible atmosphere, etc. Although nuclear criteria for each specific system may vary, pertinent nuclear environments for each category of systems are common and the ranges of criteria levels within a category are bounded within reasonable limits.

Aeronautical systems include all those systems which operate within the atmosphere. This limitation generally eliminates X-radiation and system generated electromagnetic pulse as significant threats. Figure 3 depicts the pertinent nuclear environments and representative levels of hardness which are expected in manned aircraft, the most important and complex aeronautical system. The

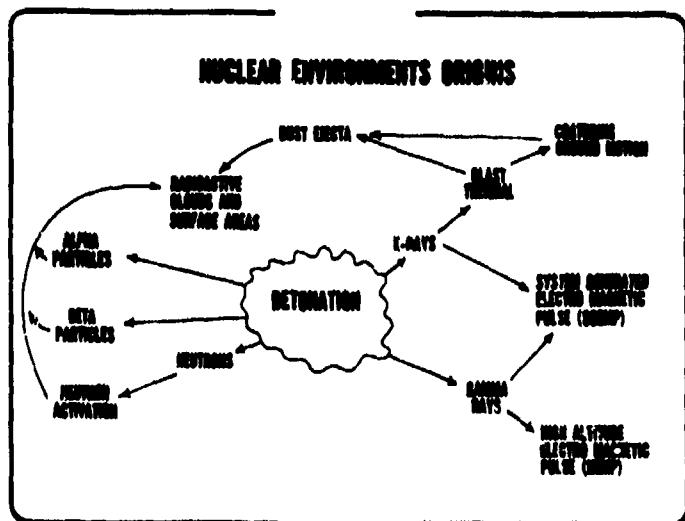


Fig. 2 - Nuclear environments - their sources and interrelationships

lower hardness level is representative of the inherent hardness expected of modern aircraft acquired with no hardness consideration. The higher is representative of the "upper-end" hardness level. Note however that no range is give for the high altitude electromagnetic pulse (EMP) environment. It is so wide-ranging, i.e. line-of-sight from the high altitude detonation, that distance from the detonation no longer has much significance. For this reason, EMP is the most significant of the nuclear environments.

#### HARDNESS CRITICALITY

A typical aeronautical system consists of literally millions of individual elements. The cost of controlling each and every element to maintain system hardness would be astronomical. However, a large percentage of the myriad of bits and pieces requires no controls since no reasonable change in their characteristics would affect hardness. The competing factors, i.e. cost and hardness assurance, mandate the investigation and evaluation of each mission critical design element to determine whether or not it is critical to the system's design hardness. If an element is hardness critical, special controls must be placed on its procurement/reprocurement, a unique part specification must be prepared, specific design information and rationale must be documented, etc. System elements, either nonmission critical or non-hardness critical, require no special attention.

A simple yes or no breakpoint for hardness criticality should be adequate for the structural components of the system. However, a modern system contains numerous sys-

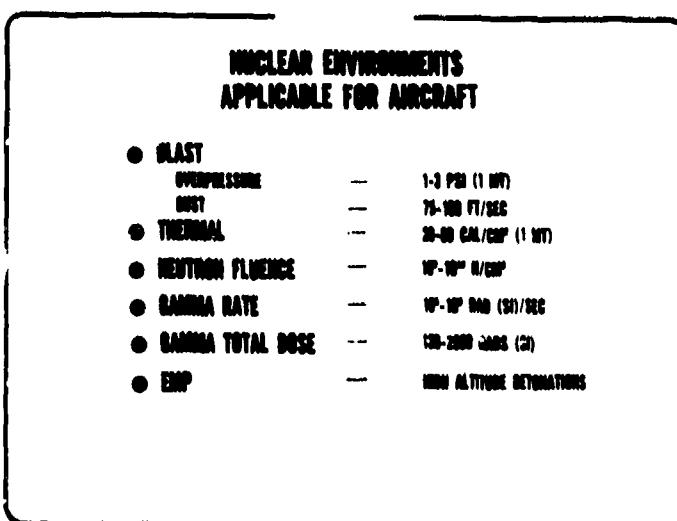


Fig. 3 - Nuclear environments pertinent to aeronautical systems and representative system hardness levels

tems utilizing semiconductors, which are potentially susceptible to nuclear radiation and EMP-generated transient voltages. In general, the electrical parameters characteristic of each part type vary because of minute differences in the construction of even seemingly identical parts. Their electrical characteristics, such as gain, follow some type of statistical distribution. Therefore, one particular part with above average characteristics may be quite hard, but replacement by another part with below-average characteristics could result in unacceptable hardness. To take this property into account, additional consideration is required in the categorization of electronic pieceparts. The method presently in use defines a mission critical piecepart to be either in hardness critical category 1 (HCC1), hardness critical category 2 (HCC2) or non hardness critical. An HCC1 part may be critical to the hardness design because 1) its design margin is small (HCC1M), 2) it is hardness dedicated (HCC1H) or 3) it is non standard (HCC1S).

Design margin generally is defined to be the ratio of the environmental level at which the part ceases to function satisfactorily to the criterion, or specified environmental level. For example, the gain of a power transistor may drop below minimum acceptable value at a neutron fluence 70 times higher than the specification - its margin would be 70 (neglecting for now the statistical nature of part response). Hardness dedicated parts are those used exclusively for hardness. They are not needed in the normal design. For example, a gamma sensor in a circumvention scheme would be

hardness dedicated (HCCIH). Such a piece-part must be specially identified to prevent its elimination years later by a zealous designer who can see no purpose to it, or to prevent its replacement by a "hard" part. (The sensor is a "soft" device, i.e. highly responsive to gamma photons). Another example is a transient voltage suppressor used to protect an interface circuit from EMP induced transients.

Non standard parts must be identified and tracked because the characteristic parameters of non standard parts can vary significantly from procurement to procurement and screening may be necessary to maintain acceptable response characteristics.

Criteria used in the determination of the hardness critical category for design elements are addressed below for each of the nuclear specification environments applicable to the aeronautical systems.

**NUCLEAR BLAST** - The nuclear blast environment is generally specified in terms of overpressure (psi) and gust (ft/sec). Overpressure generates crushing effects on the structures of aeronautical systems. Gusts are simply motion of air against the system similar to gusty winds. Generally, the system should be capable of withstanding several repetitions of these environments. Hardening of the system to withstand these environments is almost exclusively limited to the primary and secondary structure.

Components which must be design hardened specifically to the blast environment are hardness critical. Examples of possible hardness critical items are weapons bay doors and associated hardware (potentially sensitive to overpressure) and horizontal and/or vertical stabilizers (potentially sensitive to gust).

**THERMAL** - The thermal environment for the system is usually specified in terms of the thermal flux ( $\text{cal}/\text{cm}^2 \text{ sec}$ ) and the cumulative thermal fluence ( $\text{cal}/\text{cm}^2$ ). These are associated with weapon yield and detonation altitude. The system may be required to withstand several repetitions of this environment without loss of capability to complete the mission.

Hardening of the system to thermal radiation is almost exclusively associated with its external components. Exceptions to this general rule may be cockpit glare shields, thermal shields, cockpit interiors (if no thermal shields are provided) and components directly attached to the inner face of the aircraft skin. Examples of areas potentially critical to the thermal environment are composite structural components, radomes, and honeycomb panels.

A repeated exposure requirement could be cause for careful examination of the design. For example, a surface coating may

provide protection to the underlying structure for one exposure to the thermal environment, but as a result of this exposure, its reflective characteristics could be degraded so that protection is inadequate for following exposures.

Category designation for the thermal environment is similar to that for blast. If the design of a component is driven by the thermal requirement it is designated hardness critical. All other components are non hardness critical.

**NEUTRON FLUENCE** - Prompt neutrons from a nuclear detonation are high-energy neutral particles (average energies of about one million electron volts, Mev). Such particles damage the lattice structure of semiconductor devices, degrading their electrical characteristics. Such damage is cumulative so that fluence rather than flux is of more interest. The electrical parameter most affected by neutron damage, and generally most important to circuit design, is the current gain, beta (B). Therefore, design margins will be defined with reference to this parameter. Since linear integrated circuits frequently reflect a composite gain related to the internal transistors, this approach is also applicable to these devices. (In a few specific circuits, other device parameters, such as breakdown voltage and delay time, may be of greater relevance than gain. In these situations, neutron induced changes and related design margins for these other parameters should be developed in a manner similar to the gain design margins.)

Recall that design margin is defined as the ratio of the fluence value at which failure/unacceptable response occurs to the specification fluence value. Failure/unacceptable response is based on circuit level operational requirements and is taken to be the point at which the circuit operation is outside of the design tolerance limits. This is generally determined through circuit analysis utilizing piecepart test data. Thus each semiconductor piecepart degradation is related to circuit operational requirements.

An example which illustrates the definitions of design margin is presented in Figure 4. The upper curve, labeled empirical data, is a representative plot of transistor gain as a function of neutron fluence. This curve is drawn through the medians of the distribution of sample data points, and the extremes of the distribution are shown by the error bars. The lower curve is obtained by applying the average damage constant, derived from the test data, to the published minimum transistor gain. This curve passes through the minimum acceptable value of gain,  $B_{min}$ .

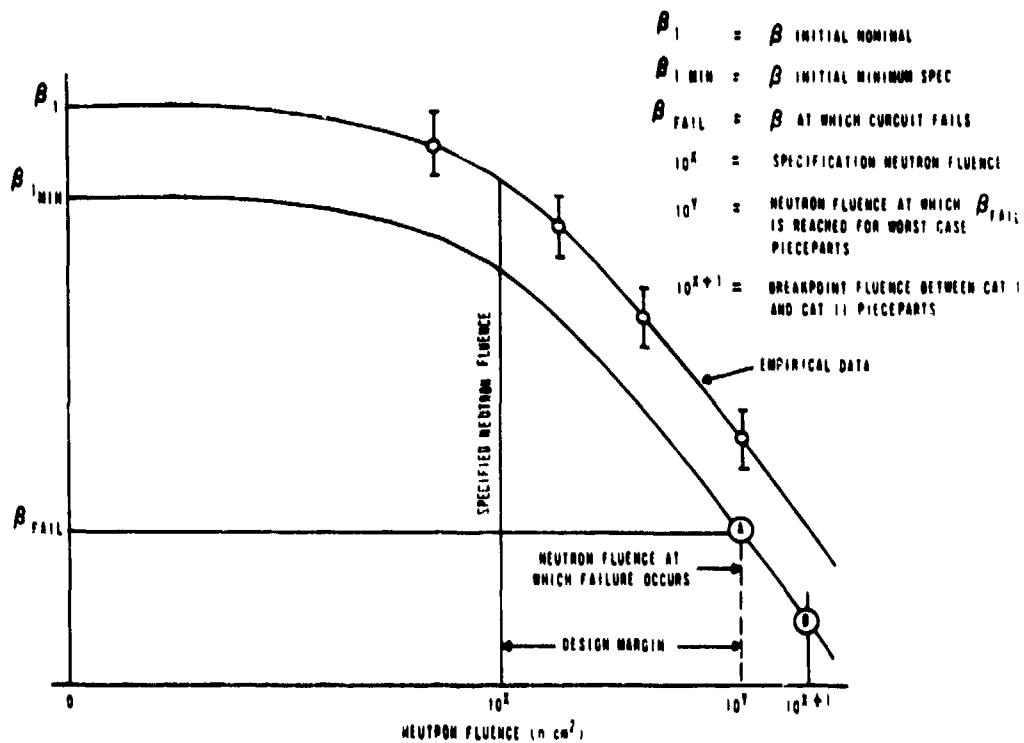


Fig. 4 - Representative piecepart response to neutron fluence

specified by the circuit designer (point A) which establishes the failure fluence level  $10^y$  ( $n/cm^2$ ). The design margin is then the ratio  $10^y/10^x$ , where  $10^x$  is the specification level. Point B is located at a fluence of  $10^{x+1}$ , that is, one order of magnitude above the specification level. If the breakpoint between HCC1M and HCC2 were an order of magnitude above specification (Point B), the designation of the piecepart is determined by whether point A is to the left (HCC1M) or right (HCC2) of Point B. The piecepart used in this example is HCC1M.

For neutron fluence, it is recommended that a design margin of an order of magnitude ( $\times 10$ ) be designated as the breakpoint between HCC1M and HCC2, and that two orders of magnitude ( $\times 100$ ) be designated as the break point between HCC2 and non hardness critical.

GAMMA DOSE RATE - Gamma dose rate is also a prompt environment occurring immediately upon detonation. A spherical shell of

gamma photons proceed outward from the detonation at the speed of light. These gammas interact with semiconductors, resulting in the freeing of electrons. These electrons comprise a current (photocurrent) which could cause burnout of the device and/or upset in both analog and digital circuits. For the moderate levels of interest to aeronautical systems, burnout is of minimum concern and can be easily prevented. Detailed criteris for categorizing analog and digital circuitry and associated components are developed in the following paragraphs. Analog circuits are circuits in which the output is a continuous function of the input variable over given range. Amplifiers and voltage regulators are generally considered analog. Digital circuits are circuits which generally operate at two discrete voltage levels.

Analog Circuits - The majority of analog circuitry and included parts will likely be designated non hardness critical

for gamma dose rate effects since for a large portion of the aeronautical system electronics, the circuit's gamma dose rate perturbation time is much shorter than the allowable transient response time at the circuit output. This allowable transient response time is based on the excitation time of the driven circuit/component. In cases where relative response times are the governing failure factors, hardness criticality may be based directly on the ratio of allowable transient response time to the perturbation time rather than on gamma dose rate (figure 5).

Analog circuitry which cannot be designated non hardness critical and those not analytically amenable to this approach should be considered from a functional standpoint. If the perturbation causes a short inoperative period, circuit blanking or possible erroneous digital information (e.g., analog/digital converters), the resultant effects on subsystem operation should be examined for significance to mission completion capability. If the only result of an analog circuit response to the gamma pulse is a brief disruption which does not significantly or permanently degrade system performance, the circuit should be designated non hardness critical for gamma dose rate. It is recommended that those analog circuits which cannot be designated as non hardness critical be categorized in accordance with figure 5.

Digital Circuits - Digital circuitry can usually be functionally classified as either transient tolerant or transient susceptible. Transient tolerant circuitry may experience perturbations or even logic level shifts although functionally the disruption does not significantly affect the mission. Circuitry used for information transfer and processing, and for control and display are often transient tolerant. The normal procedures of periodic updating, pulse integration, multiple source and parity checks, and software techniques will prevent the transients from posing a significant threat. This type of circuitry and associated pieceparts may be designated non hardness critical on a functional basis.

Transient susceptible digital circuitry in which a functional disruption or data loss cannot be tolerated must be examined carefully for transient magnitudes and response times. For digital computers and other circuitry which are not transient tolerant, loss or scrambling of stored mission-critical information can be prevented by using circumvention circuitry and associated software. Circumvention circuits are hardness dedicated and, by definition, are HCC1H. Circumvention circuits generally

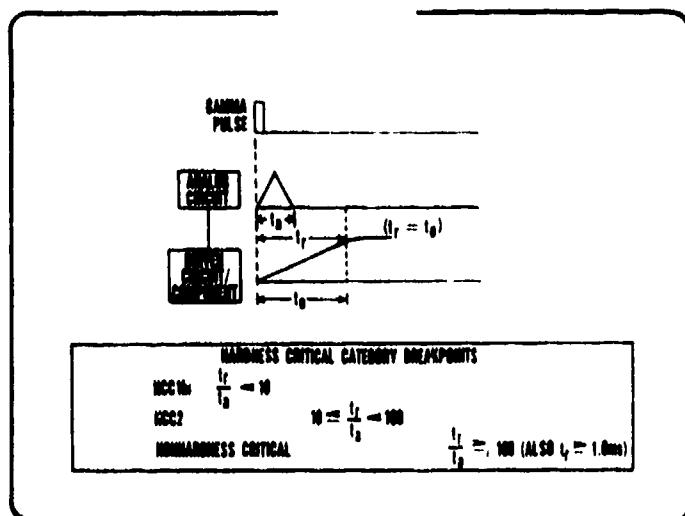


Fig. 5 - Analog circuit criticality and breakpoints

consist of a radiation detector which generates a signal upon exposure to gamma dose rate environments, conditioning circuits which provide the required transfer functions, and a clamp/diverter which directly prevents the undesired gamma response signal from reaching the protected circuitry. A simple circumvention circuit may consist of a single device (often termed a clamp) performing all of the necessary functions and may not require a software tie-in.

The hardness criticality of the piece-parts contained in circumvention and controlled circuits (figure 6) must be related to both gamma sensitivity and signal race conditions. Interrelationships exist between relative sensitivity thresholds, and also between signal propagation times and signal magnitudes at the indicated summing junction. The design intent is to assure that the circumvention circuitry gamma sensitivity threshold is adequately but not excessively below the controlled circuitry threshold and to assure that there is an adequate time margin between arrival of the circumvention signal and the controlled circuit signal at the critical summing junction.

The gamma threshold for the circumvent/divert function should occur at one order of magnitude dose rate level below the similar threshold for the controlled circuitry. Where the order of magnitude threshold margin is not achieved, the pieceparts in the circumvention network will be designated HCC1M. In some circumvention designs, the critical threshold is in the diverter section only since it acts as both a detector and a clamp. The remaining circumvention

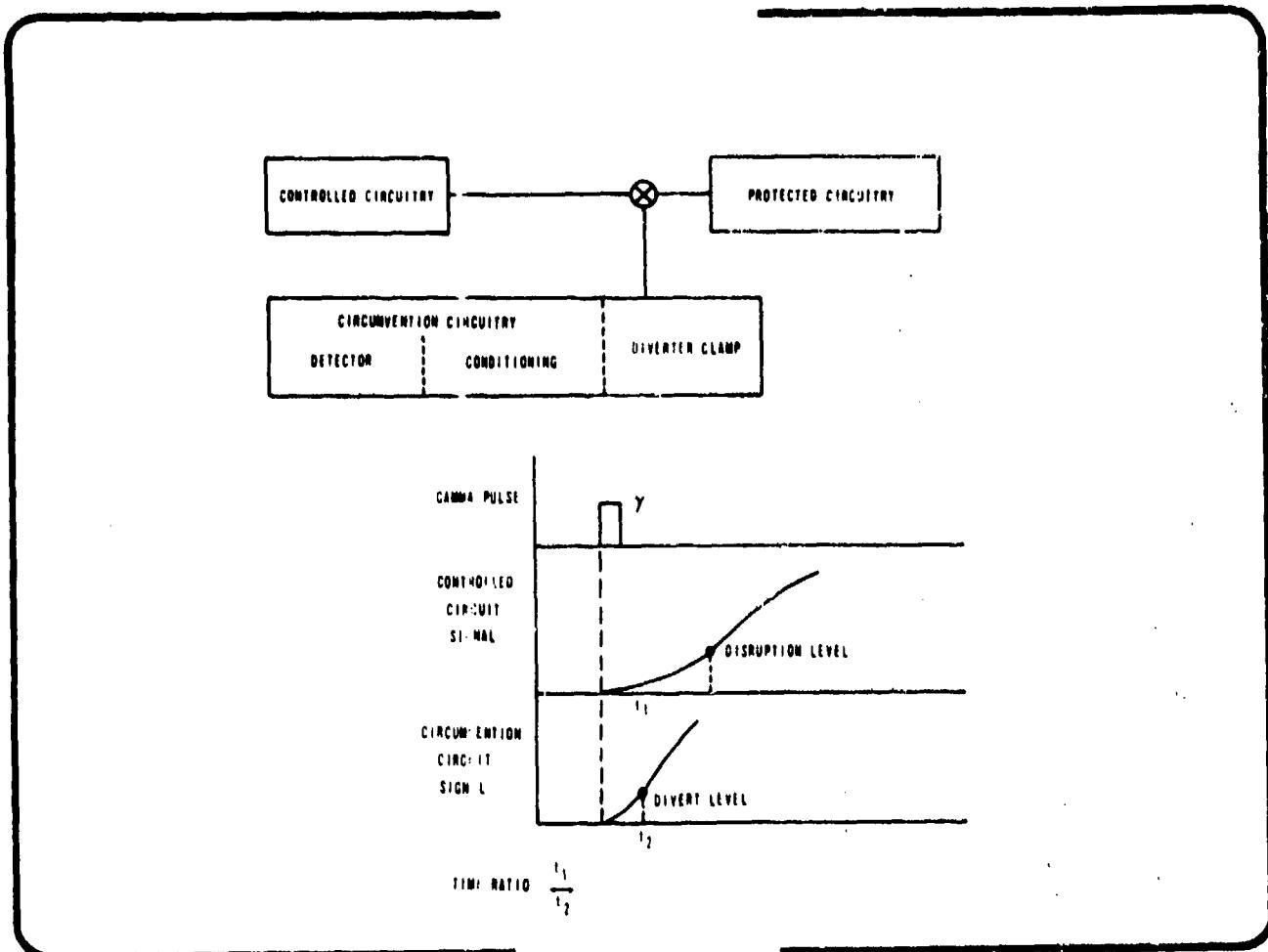


Fig. 6 - Circumvention race conditions

circuitry controls "off" time and properly sequenced restart signals.

Race conditions are interpreted to be the relationship between arrival times at the summing junction (figure 6) of the controlled circuit gamma response signal (if a magnitude related to the protected circuit "disturb" level) and an adequate magnitude diversion signal. The input threshold level for disruption of the protected circuitry (e.g., disruptive write signal in memory) is first determined. The time period for gamma response of the controlled circuit to produce this disruption level is then related to the response time of the circumvention circuit which will produce an adequate compensation or diversion signal to prevent upset of the protected circuitry.

If the time ratio of the controlled circuit response (figure 6,  $t_1$ ) to the circumvention circuit response ( $t_2$ ) is equal to or greater than 50, both the circumvention and controlled circuit pieceparts will be non hardness critical, if equal or greater than five both circumvention and

controlled circuit pieceparts will be designated HCC2. If this ratio is less than five, the circumvention circuit parts which affect the response time will be designated HCC1M to apply a degree of response time controls. If this ratio is less than two, pieceparts in both the circumvention circuit and controlled circuit which affect response time will be designated HCC1M.

Where hardness dedicated subcircuits having one or more parts are used, the subcircuit must be designated HCC1H. This could include such items as simple clamps and photocurrent compensation devices. The part(s) would be categorized based on design margin or response time considerations. Only the portion of the circuitry considered hardness dedicated is HCC1H. The intent is to assure that the hardness dedicated subcircuit is addressed properly in the design documentation.

**GAMMA TOTAL DOSE** - The total dose environment is the total amount of radiation absorbed by the pertinent system element during the time of interest. Whereas the

gamma dose rate environment is a prompt environment incurred during a microsecond or less, the total dose environment is cumulative over the entire mission. Typical sources of the total dose environment are penetrations of radioactive dust clouds (7), very low altitude fly overs of surfaces contaminated by radioactive fallout (8), and the prompt and early-time radiation from fireballs of nearby detonations (9).

For levels pertinent to aeronautical systems, the gamma total dose environment is potentially of concern only for microelectronic pieceparts utilizing metallic oxide dielectrics (e.g. MOSFETS). The gammas can interact with the semiconductor materials freeing electrons. Some electrons will be trapped in the oxide near the oxide/semiconductor interface resulting in changes to the threshold gate voltage and other characteristic parameters of the MOS devices. It is recommended that hardness critical categories be based on the following. If the design margin is 100 or greater, the piecepart should be non hardness critical; if the design margin is less than 100, but 10 or greater, the piecepart should be HCC2; and if the design margin is less than 10, it should be HCC1M.

**ELECTROMAGNETIC PULSE** - Although local EMP environments are generated by both surface and atmospheric detonations, by far the most severe EMP is generated by high altitude detonations. Such a detonation over Omaha, Nebraska would subject virtually the entire United States to near-uniform levels of EMP sufficient to threaten all non-hardened electronic systems.

The aeronautical system acts as an antenna excited by the plane wave EMP. Such excitation can result in currents of tens of thousands of amperes flowing in the conducting skin. This energy can couple into system wiring leading to interface connectors of electronic equipment.

The overall system hardening approach generally relies upon judicious utilization of shielding to decrease the energy coupling from its skin and hardening of the interface circuits of the "black boxes". Therefore both the EMP hardening approach and hardness assurance are related to system shielding and electronic equipment hardening. Hardness criticality will be defined for components and methods having significance to shielding and for equipment interface circuits and pieceparts.

An EMP hardening approach to minimize magnetic coupling and to provide shielding to attenuate the electric field effects may include a controlled-wiring/cable-routing/electrical-grounding concept, use of EMP shielded bays and interconnecting shielded

conduits, and appropriate construction and maintenance procedures. Each component of the system with a significant shielding role in the EMP hardening approach and/or whose design is impacted by the EMP requirement is, by definition, HCC1H. Examples of HCC1H components/designs are: shielded bay doors, shielded bay construction, conduits, conduit connectors, and line replaceable unit (LRU) construction (outside of shielded bays).

The electronics interface EMP specification generally is a bulk cable core current requirement or an interface connector pin current/voltage requirement. The pin specification is directly applicable to interface circuit analysis, but the bulk cable core current must be proportioned to the individual wires in the wire bundle to determine the impressed pin currents. This relationship is generally dependent on the number of wires in the cable, cable lengths and configurations, and termination impedances. However, for commonality and simplicity, the following relationships are recommended to determine the distribution of the bulk current to individual wire currents:

- Above 1 MHz, the bulk cable core current should be equally distributed among the conductors connected to the interface connector pins.
- Below 1 MHz, the bulk cable core current should be distributed among the interface connector pins according to the termination impedances at the interfaces.

Electronic interface pieceparts may be either voltage or current sensitive. However, the sensitivity can generally be related to impressed current at the connector pin by use of appropriate circuit parameters. The hardness design margin, M, (in db) is defined to be 20 times the log ratio of the current which will produce device damage,  $I_w$  (damage), to the current at the interface connector,  $I_w$  (spec).

$$M = 20 \log \frac{I_w(\text{damage})}{I_w(\text{spec})} \quad (1)$$

In determining conductor currents associated with damage to an interface piecepart, the Wunsch-Bell model for device burnout should be used (10). This model relies on the Wunsch-Bell damage factor (or the k factor) of the device. The criteria for determining the value of k to be used in calculating the  $I_w$  (damage) are: (1) when reliable, well-documented, and recent test data (such as the test data in recently developed data banks) are available, k will be taken at the lower value three-sigma point. If this

three-sigma value is not provided and it cannot be calculated based on the available information, then the k used will be the given mean k divided by three. (2) When state-of-the-art analytical techniques are used to calculate k, the k used in the analysis will be the calculated k divided by 10, (3) When k factors based on other analytical techniques (such as an approach based on device manufacturer specification sheets) or when test data are not covered by the criteria in (1) above, the k to be used in the analysis should be the estimated k divided by 50.

To correlate rectangular pulse-power damage level data to damped sine wave specifications used in many ongoing system programs, the following approach is recommended. The standard Wunsch-Bell model based on square wave pulse testing should be used for all pulses. The relationship between the power at failure,  $P_f$ , for the rectangular excitation pulse is:

$$P_f = k(w_p)^{-\frac{1}{2}} \quad (2)$$

Since  $w_p$ , the square wave pulse width can be approximated by the expression

$$w_p = \frac{1}{5f} \quad (3)$$

and is assumed to be just sufficient to fail the device, the power at failure for the damped sine wave,  $P_s$ , is:

$$P_s = k(5f)^{\frac{1}{2}} \quad (4)$$

where f is the frequency of the damped sine wave.

#### HARDNESS ASSURANCE DESIGN DOCUMENTATION

The development phase of a system acquisition program should result in a hardened baseline design which satisfies all program requirements and which has been fully verified. Production systems would be manufactured in accordance with this fixed baseline. However, this ideal situation is rarely realized. For real systems, changes to the baseline design are facts of life. They can occur for many reasons, e.g., as a result of the flight test program, because some parts and/or equipment which were utilized in the baseline are no longer available, because the technology utilized in the baseline has become obsolete, because performance requirements of the original system

have been revised, and numerous other reasons. Many of the above factors are due to the relatively long development time required for complex modern systems. By the time the baseline design has been firmed up, many facets of it may be obsolete.

Because changes in the baseline design are highly probable, hardness assurance programs must be flexible enough to adapt to these changes and remain effective. Essential to this flexibility is a detailed data base which at any given time in the acquisition program fully defines the present hardened baseline design. This data base should also contain design details and rationale for the various specific hardening techniques employed, specific information about the required characteristics of each hardness critical element of the design, and other related information. This data base is termed the hardness assurance design documentation (HADD).

In addition to providing a current definition of the hardened baseline design, the HADD is essential to the successful implementation of the various management controls required during production, and the definition of parts specifications for procurement actions during production. The HADD is also essential to the follow-on hardness maintenance efforts.

For maximum cost effectiveness, the HADD concept should be included early in the development phase. Designers should be required to maintain informal but detailed notebooks which reflect specific hardening techniques and the rationale for selection of that particular technique. Development testing and documentation should be compatible with subsequent formal documentation of the test effort, verification efforts should satisfy many of the HADD requirements, and the system technical orders should be complementary to the HADD requirements.

The HADD must be organized so that information needed to support a parts change, a configuration change, or other action can easily be found. It must also be conducive to expansion and updating as new information is generated during subsequent program phases.

The HADD is envisioned essentially as a library maintained initially at the prime contractor's facility and later at the appropriate logistic support centers. This library would be maintained in an area convenient to the various users and access would be controlled to assure the data remained intact. Microfilm and/or microfiche could be used where feasible to reduce bulk and full time custodians would be assigned for security, cataloging, filing, and support of the users.

Much information required for the HA program will be available in other program documentation, such as technical orders, design verification reports, Part II Specifications and Failure Analysis Reports. This information should be incorporated into the HADD by reference, and copies of these reports should be maintained as a part of the HADD library. Data required, but which is not available in existing sources, should be generated and documented in the HADD.

Requirements differ as to the degree and amount of data needed for HCC1 and 2. The specific data required for both categories are defined in subsequent paragraphs. Most HCC2 and all non hardness critical part data requirements should be satisfied by standard program documentation.

The following discussion is divided between mechanical and structural elements which are related to blast, thermal and EMP shielding/bonding, and electrical/electronics equipment which are related to nuclear radiation and EMP interface effects.

**MECHANICAL/STRUCTURAL COMPONENTS** - The HADD will include engineering drawings showing details of construction, materials, tolerances, and other relevant characteristics or will provide references to this information included in normally deliverable documentation. The hardness criticality category of each part will be listed as a function of the nuclear environment for which it is hardness critical, i.e., EMP, blast, or thermal. Reasons for designating parts as hardness critical and the hardness design techniques (and rationale for these techniques) used to attain the required hardness will be discussed. If any special manufacturing techniques, materials, tolerances, etc., are required for hardness, appropriate documentation must be made. For example, the type of adhesive in a honeycomb panel as well as the bonding technique, may be essential to the thermal hardness of the panel. Shielded avionic bay construction, conduits, details of wing raceways, and other portions of structural design which are hardness critical for EMP should be discussed in detail. Elements which are neither electrical/electronic nor structural such as cable runs, connectors, EMP seals on LRU cases, and other like items which are required for EMP hardness must be described.

**ELECTRICAL/ELECTRONIC PIECEPARTS** - The information to be documented for inclusion in the HADD in support of nuclear radiation and electronic interface EMP hardness assurance is presented in the following outline. The information requirements addressed under Subsystem Description applies to all mission critical subsystems. Hardness critical categories for control purposes are applied

at the part and circuit levels, but should not extend to the subsystem level. The subsystem information specified is that which should be required and which normally should be developed for systems analysis. Some of this information will be included in deliverable documentation and should be included in the HADD by reference only. At the circuit and parts level a division is made between documentation requirements for HCC1 and HCC2.

(1) Subsystem Description (all mission critical subsystems).

(a) Operational description/functional flow diagrams.

(b) Period of mission when subsystem is operational.

(c) Software: complete descriptive material and programs which have any direct bearing on nuclear survivability.

(d) Subsystem functional requirements in terms of nominal and tolerance values (ideally, the subsystem functional requirements and tolerance dictate the requirements and tolerances at the circuit and piecepart levels).

(e) Subsystem interconnecting wiring diagrams which permit determination of interconnections to the circuit level, adequate nomenclature to determine if interconnecting cabling is carried between modules (LRUs), and actual locations of cable runs.

(f) Appropriate discussions of any subsystem level approach used to achieve the required hardness.

(2) Circuit Description (Items with \* apply to circuit or piecepart HCC2, while the entire list applies to HCC1).

Information addressing each HCC1 and HCC2 circuit in the subsystem must be presented and will include, as a minimum, the following:

\*(a) Circuit schematic.

(b) A general electrical description of the operation of the circuit.

(c) Circuit functional requirements in terms of nominal and tolerance values.

(d) A listing for each circuit interface point with pertinent nominal and tolerance values of electrical parameters (e.g., voltages, currents as applicable), wave forms, and special timing relationships.

(e) Discussion of the approach by which the circuit hardening to the radiation and EMP interface environments was achieved (this will include derating factors, design techniques, parts selection, and any special relevance of passive parts).

\*(f) A presentation of allowable responses at the relevant circuit terminals.

(g) Predicted/observed radiation and EMP interface circuit responses (at the circuit and piecepart levels) as related to the allowable responses determined for (f) above.

(3) Pieceparts (Items with \* apply to circuit or piecepart HCC2, while the entire list applies to HCC1).

A complete pieceparts list is required and will include, as a minimum, the following:

\*(a) For passive pieceparts, the value and tolerances of electrical parameters (e.g., resistance, capacitance), part numbers, and any special hardness considerations.

\*(b) For active devices, piecepart designation and MIL-STD or applicable manufacturer's hi-rel specification, specific circuit application/location, values of relevant electrical parameters and design margins used in the design considerations, and analyses including typical min/max values as appropriate for each location; radiation response information with reference to the information source to include relevant gamma rate, gamma total dose, and neutron fluence effects data (in cases where the observed test response is quite complex (e.g., possibly op-amp gamma response for different initial conditions), a summary of the data may be presented with reference to the documented test data).

(c) Manufacturer and any special controls screening or qualification testing specified for the pieceparts.

\*(d) Each interface piecepart must be addressed in terms of relevant electrical characteristics, tolerances, design margins, junction breakdown levels, surge impedance transient susceptibility or k-factor, and anticipated EMP-generated current/voltage level impressed.

Electrical parts such as solenoids, motors and other simple electrical devices should also be discussed in the HADD including appropriate hardening rationale and selection criteria. The critical concern for these items will generally be the dielectric withstanding voltage (DWV) requirement. Special design features, such as use of surge suppression devices, should be discussed in detail.

It should be emphasized that extensive documentation is required for HCC1 circuits and subcircuits. However, the pieceparts contained in these circuits or subcircuits may be HCC2, or non-hardness critical. In this case, only the circuit must be addressed in detail.

**ORGANIZATION AND FORMAT** - The HADD should consist of an introductory volume (Volume I); a listing of hardness critical

items (Volume II); an HA Plan (Volume III); and a volume for each subsystem.

Volume I should contain the system nuclear criteria and supporting analyses, (if available), the system specifications and supporting analyses, and the hardening approaches for the specified nuclear environments. (Specific circuit/piecepart/component/equipment approaches should be explained in the appropriate subsystem volume.) This discussion should include design guidelines and restrictions provided to circuit designers, derating factors and how they were derived, rationale for shielding allocations, thermal hardening approaches, etc. Volume I should also contain instructions on use of the HADD.

Volume II should contain a detailed listing of the hardness critical items (HCI) and the nuclear environment for which they are critical. For each HCCI item the basis for which it is HCCI will be explained. The format of this volume will be tiered by subsystem, LRU, module, circuit, and piecepart so that cross referencing from the overall HADD to the HCI listing is simplified.

Volume III should consist of an HA Plan which should be developed during RDT&E. The HA Plan should explain the managerial, organizational, and technical aspects of the HA program and should contain the configuration control, quality control, and parts control procedures, and the methods used in developing parts specifications.

Each subsystem volume should contain specific hardening approaches, techniques, and other pertinent information as discussed in previous paragraphs and will be organized on a tier basis, that is, the subsystem will be discussed, then subdivisions for the next tier (e.g., LRUs) will be discussed, and so on to the circuit level. A piecepart list should be prepared for each circuit relating part location and hardness considerations. The specific information described in paragraph 3 (b) above should be provided for each piecepart.

Each associate contractor should prepare a Volume I, Volume II, and Volume III applicable to their specific responsibility and equipment. The prime (or designated associate) contractor should establish a volume numbering system and assign volume numbers i.e., (volume IV and higher) to the associate contractors. The outline, format, and organization of each subsystem volume should be established so that all subsystem volumes for a particular system will be similar in organization and content.

## PARTS SPECIFICATIONS

An essential part of the HA program is parts control. Parts control should be achieved through development and utilization of parts specifications to ensure that procurement actions provide the desired parts. In the following paragraphs separate descriptions for specification requirements for mechanical/structural components and electronic pieceparts are presented. This division is appropriate because of the different nuclear hardening considerations applicable to each category. Blast, thermal, and EMP shielding considerations are pertinent to the first, while nuclear radiation and EMP hardness considerations are pertinent to the second.

**MECHANICAL/STRUCTURAL COMPONENTS** - Control of mechanical/structural components using specifications should be relatively straightforward. Each component is listed in the HADD along with its hardness criticality. The design of hardness critical items has been impacted by one or more of the applicable nuclear environments. The specifications for these items then must describe the specific requirements necessary to ensure that the procured items conform to the hardened design. Any special manufacturing controls, tolerances, material, etc., must be listed in detail in the specification. The type of verification required, if any, and the details of verification/acceptance should be specified.

The designs of non hardness critical items, by definition, are not driven by nuclear hardening requirements. Therefore, the specifications for these items should not be impacted by the nuclear hardening requirements. However, it should be emphasized that any changes in the components, such as material, manufacturing process, or dimensions during procurement are subject to configuration control and must be evaluated for hardness impact prior to approval.

**ELECTRICAL/ELECTRONIC PIECEPARTS** - Electrical parts are those parts other than mechanical/structural components or electronic pieceparts such as transistors, resistors, inductors, capacitors, integrated circuits, and other similar parts. Examples of electrical parts are solenoids, motors, and other simple electrical devices.

In general, electrical parts are relatively easy to describe and the specifications which govern their procurement are straightforward. Nuclear radiation effects on electrical parts will generally be negligible. (Electrical components which incorporate integral semiconductor controls will be considered

electronic.) A typical EMP interface requirement of a maximum impressed transient pin voltage generally is the major hardening concern for simple electrical devices. If a dielectric withstand voltage (DWV) requirement has been shown to satisfy transient pin voltage requirement, then the specification may reflect this DWV requirement rather than the transient voltage requirement.

The electronic pieceparts control problem is considerably more complicated, although discrete passive devices such as resistors, capacitors, and inductors are generally not significantly affected at moderate nuclear environment levels. The complication arises because of the extensive use of semiconductor devices. These devices are potentially susceptible to nuclear radiation and EMP-induced voltages/currents. The distribution of responses of semiconductor devices to nuclear environments may vary between piecepart types and even for pieceparts of the same type, but different manufacturer, different batch, and different lot. The variation for a particular piecepart type could be due to different manufacturing techniques, construction, etc., even though units are interchangeable. However, for a high reliability manufacturing process (i.e., one in which the yield is high and the manufacturing process is "perfected") the nuclear response should be reasonably uniform.

No special parts specifications are needed for non hardness critical pieceparts. Normal procurement practices should be followed. For HCC2 pieceparts, the only requirement is that they be procured subject to MIL-STD-38510(11) or MIL-STD-19500(12). The former governs procurement of microcircuits, and the latter discrete semiconductor devices. Since these two military standards are usually included in the system procurement requirements, the use of these requirements to control HCC2 pieceparts should pose little extra effort. The rationale for this action is that only pieceparts from "mature" processes will be qualified as military standard items. Such pieceparts generally have relatively tight response distributions which provide a reasonable degree of confidence that the piecepart (which has a relatively large design margin) will not compromise system hardness.

HCC1 pieceparts are another story. Recall that a piecepart may be designated as HCC1 either because of its small design margin (HCC1M), its hardness dedication (HCC1H), or its being non standard(HCC1S) (i.e. it is not available as a MIL-STD item.)

An HCC1M piecepart, even though it is procured under MIL-STD requirements, has a response distribution which virtually guarantees that some percentage of a large number of procured pieceparts would compromise system hardness. To prevent such an occurrence, controls may be required so that only acceptable pieceparts are used. Such requirements would be above and beyond the normal MIL-STD requirements and would probably increase the procurement cost.

HCC1H pieceparts will require only HCC2 procurement specifications. If HCC1H pieceparts do not meet HCC2 design margin requirements, they are HCC1M. HCC1M categorizations takes precedence over HCC1H. The hardness critical designation (HCC1H) is primarily a special identifier to insure adequate treatment in the HADD and during subsequent redesign/reprocurement actions.

Pieceparts not procurable under the pertinent military standard are suspect because they are not manufactured under MIL-STD control. The nuclear responses of such pieceparts could vary significantly with lot, and even over a lot. Therefore, although the design margin may be large, (i.e. in the HCC2 area for design margin) the large variation in response could result in compromise of system hardness. Maximum effort should be made to eliminate nonstandard piecepart from the design during the development phase. In many cases, the piecepart is the result of a mature process, but the vendor has not qualified it. In such a case, the vendor may have an in-house program with requirements comparable to those of the military standard. Upon Air Force approval, pieceparts from such a vendor may be treated in the same manner as MIL-STD parts until the vendor qualifies the parts to the pertinent military standard.

All piecepart  $f_t$  will have a radiation response data base developed to support the design and procurement. This data base will take into consideration environmental relevance, e.g., if gamma-induced photocurrent is not a relevant hardening factor, such photocurrent data need not be generated. The piecepart specification should not include radiation simulation testing as a requirement unless absolutely necessary. Actual radiation test characterization of parts is both expensive and tends to generate a technical problem not generally understood by procurement personnel and parts manufacturers. The parts specification should be based on acceptance values for known electrical parameters. With this approach, the electrical screening requirements generally can be performed on automated production line equipment by the parts manufacturer for a relatively small cost.

The following paragraphs address the specification requirements for each of the radiation environments for hardness critical (HCC1) pieceparts.

Neutron Fluence - The predominant effect of neutron damage to semiconductor pieceparts is a reduction in current gain. This is noticeable in discrete transistors and in the composite gain of transistors in an integrated circuit.

When a transistor is designated HCC1 based on design margin and neutron-induced gain loss, electrical screening for gain, gain-bandwidth product or both may be levied in the part specification to truncate the response distribution and achieve an acceptable margin. Good correlation has been found between the gain-bandwidth product ( $f_t$ ) and neutron induced gain degradation. This correlation is expressed in the form (ref 13).

$$\frac{1}{B} - \frac{1}{B_0} = \frac{N}{6.28 f_t K} \quad (5)$$

where

B is the gain following neutron irradiation

$B_0$  is the gain prior to neutron irradiation

N is the neutron fluence ( $n/cm^2$ )

K is the damage factor associated with neutron degradation

$f_t$  is the gain-bandwidth product

In a few circuit applications, other electrical parameters such as breakdown voltage or propagation time can be more critical than gain. Electrical screens for neutron damage correlation applicable to these parameters are either nonexistent or not well-established. For the majority of semiconductor devices other than bipolar transistors, there is also a lack of neutron damage correlation factors. If a contractor elects to specify an electrical screen other than B or the  $f_t$  screen, supporting data justifying the screen must be generated.

When HCC1M parts have a neutron design margin less than a factor of five, consideration should be given to parts substitution/ circuit redesign. The cost effectiveness of stringent controls as opposed to parts substitution/redesign, should be studied and the most economical approach taken.

Gamma Dose Rate - The majority of the electronic pieceparts in an aeronautical system should be non hardness critical for the gamma dose rate environment unless they are part of a digital processing circumvention scheme. (An example of an exception could be a light emitting diode

(LED) in a data entry unit. LEDs are quite sensitive to gamma dose rate and may well be hardness critical.) This is very fortunate because of the high cost associated with the imposition of a gamma dose rate specification on piecepart procurement. There currently exists no convenient electrical parameter screens for photo current induced by gamma dose rate. Therefore, screening using a gamma dose rate simulation facility (e.g., linear accelerator, or flash X-ray) would be necessary to satisfy the requirement. Rather than imposing direct specification control of the photocurrent response of semiconductor pieceparts to gamma dose rate, control will probably be exercised over parameters such as rise times, propagation times, and saturation recovery times which are critical for adequate circuit operation.

The following approach is suggested for characterization or screening of HCCIH circumvention/clamp circuitry and any other gamma hardness dedicated subcircuits and pieceparts. Radiation testing should be performed at an electronics construction level that will exercise as a unit the circumvention/clamp, controlled circuits, and pieceparts. That is, the combined circuitry should be properly connected and operationally tested. Test point monitoring should provide essential information on those parameters (e.g., sensitivity thresholds, response magnitudes, and race conditions) required for determination of response margins and distributions. The objective is to ascertain operational response for the normally configured circuitry and to determine response sensitivity, times and magnitudes for the critical subelements (e.g., radiation detector).

Testing requirements should be based on predicted criticality for each HCCIH circuit. Initially a large fraction (up to 100 percent) of the circuits or pieceparts may have to be tested. When proper operation has been established and the corresponding response distribution indicates that a small random sample provides an acceptable risk, further testing may be reduced or terminated. For instance, a computer with circumvention may analytically be shown to have a small design margin in race time. The test requirements may call for 100 percent testing of the first 20 units with a prescribed decrease in sample size if no units fail. If a significant number of failures are observed, failure mode analysis should be performed to determine the cause. If test data confirms that a test of only a portion of the HCCIH circuit is required, then a reduced test effort should be possible. For instance, it may be found

that control and controlled circuitry operate well within prescribed sensitivity limits, but fluctuations in sensitivity of the radiation detectors may cause problems. In this case, a simplified screening test of the detector alone may be adequate.

Gamma Total Dose - Gamma total dose levels on manned aeronautical systems are generally moderate with respect to the majority of electronics equipment susceptibility levels. The total dose sensitivities of most electronics pieceparts are significantly above the human tolerance level. Thus most electronics pieceparts may be dismissed as nonsusceptible at the total dose specification level. A few piecepart types including MOS devices, high gain operational amplifiers and bipolar devices operated at very low bias current levels may be susceptible.

Gamma total dose degrading effects are considered cumulative and permanent. Annealing of the total dose effects is unreliable and not an acceptable factor in susceptibility determination. Thus, the total dose should be considered to be acquired in a short period of time, and no annealing of the damage should be considered.

There currently exist no adequate electrical characterization methods which are relatable to gamma dose susceptibility predictions. The majority of pieceparts are expected to be qualified to total dose requirements through proper adjustment of the neutron/gamma ratio during reactor testing for neutron response. When it is apparent from this testing or earlier test data that a total dose problem may exist, total dose testing should be performed at a gamma facility such as a cobalt 60 source. Thus, any piecepart specification where total dose problems exist must be addressed in terms of radiation testing with appropriate lot control and sampling techniques.

Electromagnetic Pulse - A great deal of electronic equipment makes use of surge suppression devices, isolation transformers, bandpass filters, and other EMP hardness dedicated circuits and parts (at the interfaces) to electrically isolate sensitive components of LRU circuitry from connector interface EMP signals. Even though these devices are designated HCCIH (hardness dedicated items), there are no requirements for special controls if specified current and voltage handling capabilities are adequate to provide more than 10 db margin to the devices themselves and to the circuits they protect.

For semiconductor components at or near the interface that have less than 10 dB hardness margin (HCCIM), electrical parameters which can be correlated to the

damage factor will be specified and controlled to assure equipment EMP hardness. In the case of semiconductor devices for which there are no known electrical parameters which correlate to the damage factor, pulse testing will be required to initially qualify the device, and periodic small sample testing should be included in the part procurement specification to ensure that subsequent production units remain acceptable.

#### Consolidation of Piecepart Requirements

There are likely to be situations in which a particular piecepart type is used in a number of different circuit locations. The piecepart may be designated HCC2 in some of the locations and HCC1M in the remaining locations because of varying socket design margins. A review of the part type and application should be made to determine the cost-effective approach to the part type procurement. The review should consider relative quantities in HCC1M and HCC2, HCC1M design margins in the various locations and the possibility of minor redesign for near HCC2 cases to produce HCC2 design margins. Based on this review a determination can be made as to whether all parts should be procured to a single HCC1M specification or if a portion should be procured to HCC2 specifications and the remainder to one or more HCC1M specifications.

#### PROGRAM MANAGEMENT

The previous sections discussed the prerequisites necessary for an effective and affordable hardness assurance program. The successful completion of those efforts will now be assumed. This section consists of a discussion of the major management efforts required during the production phase to ensure that the hardened design is reflected in each of the systems turned over to the user.

Probably the one most critical part of a successful hardness assurance program is its program manager. Hardness assurance tasks will influence and impact almost all company divisions from engineering to procurement. Only an aggressive and knowledgeable individual with top-level management support can overcome the resistance from the "we've always done it this way" crowd.

Maintaining the hardening design during the production phase can be achieved through three major management efforts, configuration control, quality control, and parts control. Configuration control consists of those actions which are required to ensure that no changes are made to the baseline hardened design (as defined by the HADD) without review and approval. Quality

control procedures must be formulated and implemented to ensure that hardness is not inadvertently compromised during manufacture. Parts control procedures must be implemented to ensure that the lowest tier elements conform to the baseline hardened design.

Military Standards applicable to these programs are MIL-STD-480, MIL-Q-9858A, and MIL-STD-891 for configuration control, quality control, and parts control, respectively (refs. 14, 15, and 16). Specific nuclear hardness related activities required for hardness assurance should be integrated into the existing framework of the standard programs to minimize duplication of effort and cost. The prime contractor(s) must also ensure that components/equipment procured from subcontractors is subjected to the same type of controls.

**CONFIGURATION CONTROL** - In this paper a change is any action which results in a departure from the baseline hardened design as defined in the HADD. Examples of changes are replacement of any structural element, such as a rivet or panel, by one not meeting the original requirements (different material, different manufacturing process, different tolerances, different coating, different dimensions, etc.); replacement of an electronic piecepart by one of a different type, or different construction or manufacturing process (even though the electrical characteristics may be identical); circuit redesign; any and all redesigns of structure or subsystem; and changes in system software having a direct relationship to hardness.

To ensure that all changes are subject to careful examination and approval prior to implementation, a Configuration Control Board (CCB) must be established by each contractor (Fig 7). A nuclear hardness specialist familiar with all respects of the hardened design must be a permanent member of the CCB or have signoff authority on all changes. This board must have approval authority over all changes in the baseline configuration. Changes resulting in different parts specifications or characteristics of the parts used in the design must be referred to the Parts Control Board (PCB). All changes must be evaluated by the nuclear hardness specialist with assistance coming from the staff of the nuclear hardness section and other engineering sections as required. This evaluation must include the impact on the hardness of the system, the cost, the effect on the hardness assurance and subsequent hardness maintenance/surveillance programs, and recommendations for alternate approaches. Thus, attached to each change proposal will be the evaluation of the change with respect to system hardness, consequences of the change if

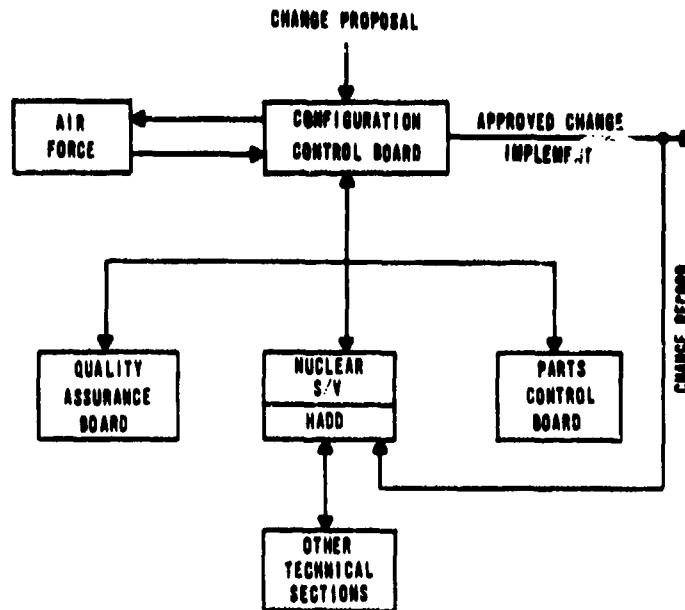


Fig. 7 - Configuration control setup

approved, and the recommended position on the change (approval/disapproval). If approved, the CCB would then forward the recommended change with the results of the evaluation for Air Force approval.

The following example is presented to illustrate CCB actions. Suppose a particular electronic circuit requires redesign for performance reasons. The circuit had been HCC2 and was composed of pieceparts which were also HCC2. The proposed modification could result in several of the pieceparts becoming HCC1M. Therefore, these pieceparts would now be subject to more stringent procurement controls, and there could be a significant cost impact associated with the modification. This would be reported to the CCB. The CCB may require investigation to determine if another approach to the problem might yield a modification which would solve the original problem and not create a significant impact on MA costs.

The need for change may result from initial operational experience, revised requirements, production difficulties, parts

acquisition problems, etc. These must all be coordinated through the CCB. Many configuration changes, such as circuit redesign, require new parts and revised manufacturing procedures. Therefore the change proposal must go to the Parts Control Board for action on parts, and to the Quality Assurance Board (QAB) to ensure that appropriate quality assurance procedures are developed for the new configuration.

The HADD plays an essential role in this change control. Reference to the HADD can be made to check the baseline design and to determine the hardness criticality of the elements for which changes are being recommended. The HADD must be updated with all approved changes. After Air Force approval, the changes are sent to the appropriate agency for implementation and to the HADD section to update the baseline design.

It is emphasized that all mission critical equipment and elements thereof are subject to this strict change control and not just the HCC1 hardness critical items. (In fact, since the CCB is the vehicle for all

configuration control, all system elements, even non mission critical, will be controlled by the CCB and maintained in the HADD.) It is this strict control which allows the implementation of a cost-effective HA program.

QUALITY ASSURANCE - Quality assurance ensures the output of the assembly/manufacturing process conforms to the baseline hardened design. The quality assurance procedures required for hardness assurance will be incorporated in the normal QA program governed by MIL-Q-9658A.

A prerequisite task to quality assurance inspections is the translation of applicable design parameters and hardening approaches into specific manufacturing/assembly instructions to ensure that design hardness is maintained. These instructions must be clear, concise, and specific so that a technician can implement them in such a manner that the configuration defined in the baseline design is achieved. Areas requiring QAB control include connector torque requirements necessary for adequate EMP shielding effectiveness; intra-LRU wire routing to minimize coupling to interior circuits from EMP interface circuits; proper cable shield terminations; circumvention/clamp circuit configuration requirements necessary for satisfactory operation of these circuits; LRU, conduit, and hydraulic/fuel line bonding; and avionics shielded bay door installation. Those procedures, drawings, work instructions, etc., involving hardness critical items, must be clearly flagged to indicate that they are critical elements in the hardness assurance effort.

The task of developing QA procedures should be a combined effort between personnel of the hardness group and appropriate production personnel. These procedures will be incorporated into the overall system and subsystem manufacturing and assembly QA procedures, which will be maintained current as part of the HADD library.

The next task is to examine the manufacturing processes and select and document those procedures which must be monitored by qualified inspectors and to identify points in the manufacturing/assembly where inspections are required to ensure the quality of the process. Included in this task may be the definition of connector torque tests, "sniffer" tests of RF gaskets, LRU current injection tests for EMP, and LRU nuclear radiation tests. The rationale for these tests should be documented in detail to support any specific nuclear hardness quality assurance testing. The inspection and test procedures related to HC items should be

flagged such that they cannot be changed without approval of the nuclear hardness section.

The managerial control exercised in the QA program will be centralized in the contractor QAB. After completing the definition of the detailed program, the QAB will ensure maximum effectiveness and prevent changes to the program which could degrade hardness. (Layout will be similar to that of the CCB as depicted in figure 7).

The nuclear hardening features of the QA program should be documented and maintained in the HADD. The QAB should evaluate all proposed changes to the program prior to implementation. All changes should be coordinated with the nuclear hardness section, and new procedures related to nuclear hardening should be appropriately flagged. Occasionally, changes in manufacturing/installation procedures will mandate redesigning and/or parts changes. In these cases, coordination between the CCB and PCB is required and if the changes are approved, then appropriate action by the CCB and PCB is required.

PARTS CONTROL - Standard program parts control procedures are described in MIL-STD-891 (USAF). The parts control program should conform to these standard requirements to the maximum extent possible. However, the standard program must be expanded to include nuclear hardening aspects and to include coverage of all types of parts. The primary method of parts control should be the development of parts specifications which reflect the requirements and characteristics necessary for part conformance to the baseline hardened design.

For purposes of this discussion, it is assumed a complete set of parts specifications has been developed (and maintained current as part of the HADD library). The PCB must maintain the baseline parts specifications in a current status and ensure that all procurement actions incorporate the appropriate specifications. The PCB should also evaluate and minimize additions to the parts list. Changes in any basic part may have serious effects at a higher tier level in the design. For example, a simple resistor change could seriously impact circuit characteristics and the hardness criticality of many associated pieceparts. A change in a structural component could impact blast, thermal or EMP hardness. Thus, a part change represents a departure from the baseline configuration and must be referred to the CCB.

The PCB flow of events is similar to that for the CCB (figure 7). The parts specifications should be kept current by the PCB. A complete set of the parts specifica-

tions should be maintained as a part of the HADD.

## CONCLUSIONS

Hardness assurance is a critical part of the life cycle survivability program and must be integrated into the entire acquisition process. A program based on the above considerations must be developed and implemented to achieve affordable system survivability over its procurement and operational life.

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Printed in U.S.A.